

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<small>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</small>					
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.					
1. REPORT DATE (DD-MM-YYYY) 26 JAN 07		2. REPORT TYPE FINAL REPORT		3. DATES COVERED (From - To) 3 SEP 03 TO 2 SEP 05	
4. TITLE AND SUBTITLE USING ADVANCED TABU SEARCH APPROACHES TO PERFORM ENHANCED AIR MOBILITY COMMAND OPERATIONAL AIRLIFT ANALYSES - PHASES II AND III				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER F49620-03-1-0100	
				5c. PROGRAM ELEMENT NUMBER 61102F	
				5d. PROJECT NUMBER 2304	
6. AUTHOR(S) PROF J. WESLEY BARNES				5e. TASK NUMBER DX	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) THE UNIVERSITY OF TEXAS AT AUSTIN MECHANICAL ENGINEERING DEPT. ETC 5.160 AUSTIN, TX 78712-7726				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NM 875 NORTH RANDOLPH STREET SUITE 325, ROOM 3112 ARLINGTON VA 22203-1768 <i>Todd E Combs/NM</i>				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT APPROVE FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT First, we focus on "transitions" (cases where our work is slated for use in either an AMC technology application or in an important application arenas essential to the economic and environmental well being of the nation). Second, we address the theoretical contributions associated with neighborhood and landscape theory. The last 12 months have been intriguing, challenging, and productive. Much has been accomplished and we eagerly look forward to the future challenges that will be met and overcome in achieving the Consortium project objectives.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)

Final
Progress Report for

**Using Advanced Tabu Search Approaches to Perform
Enhanced Air Mobility Command Operational Airlift Analyses – Phases II and III**

Period from September 1, 2005 to August 31, 2006

Principal Investigator: J. Wesley Barnes

Grant Numbers: F49620-03-1-0100 & FA9550-06-1-0052
The University of Texas at Austin

Table of Contents

Summary Status of Effort	3
Associated Personnel	4
Publications	9
Interactions	10
Accomplishments	11
Conclusion	13
References Cited in this Report	14
Appendix A	15

Summary Status of Effort

Since a separate report on the Consortium Activity at the Air Force Institute of Technology (AFIT) will be provided by Dr. James Moore, the primary content of this progress report will address Consortium activities directly associated with efforts within the Graduate Program in Operations Research and Industrial Engineering (ORIE) at The University of Texas at Austin (UT).

During the 12 month period starting 1 September 2005, substantial progress associated with the objectives stated in the AMC-AFIT-UT Consortium's research proposals ("Phases II & III") has been achieved:

Building on the **exceptional** and **unprecedented** achievements of the first 6 years of Consortium efforts, significant inroads have been accomplished on key Phase II and III application activities, selected by AMC and USTRANSCOM, that hold remarkable potential for significantly improving the warfighting capability of the USAF. These Phase II and III activities are documented in the research proposal, "Advanced Air Mobility Command Operational Airlift Analyses Using Group Theoretic Metaheuristics, Phase II, A Consortium Proposal" submitted to AFOSR in July 2002, in the Progress Reports submitted in August 2003, in August 2004 and in August 2005 and in the research proposal, "Using Advanced Tabu Search Approaches to Perform Enhanced Air Mobility Command Operational Airlift Analyses, Phase III, A Consortium Proposal" submitted to AFOSR in July, 2005. Funding for Phase III was issued in February, 2006 and the grant period for the Phase II funding was kindly extended to 15 July 2006 (from 14 January 2006) to assist in the continuity of this research.

- One PhD student and three MS students have completed their Consortium research projects and graduated from ORIE at UT during this report period. Four PhD students and four MS students are currently associated with the Consortium at ORIE-UT. Two military officers are joining the Graduate Program in ORIE in the Fall 2006 semester. Historically, the great majority of such students have joined in the Consortium's research efforts after their initial studies are completed.
- As described in detail in the Interactions and Associated Personnel sections of this report, Dr. Barnes and his students have been diligent both in enhancing the already vigorous dialogue that exists between the participants in the Consortium and in seeking out contacts and disseminating information beyond the immediate members of the Consortium. In so doing, we have conferred with influential individuals including persons associated with the US Military Academy at West Point, Wright State University, the On Time Systems Company, AFIT-ENG, the Air Force Research Laboratories/Human Effectiveness Directorate (AFRL/HECI), The Texas A&M Medical Center, AFRL/IF, the Mitre Corporation, the Austin Logistics Company, Navitaire Inc., The United States Transportation Command (USTRANSCOM), the US Army Operational Testing Command (US-OTC), the Jackson School of Geosciences at UT, the Thermal/Fluid Systems Faculty in the Mechanical Engineering Department at UT, The Institute for Advanced Technology (IAT), the Department of Philosophy at UT, and Delta Technology. In addition, Dr. Barnes, his students, and associates have made presentations at the 74th MORS Symposium, for USTRANSCOM, AFRL, AMC, Mitre Inc., Navitaire Inc, at the AFOSR Optimization and Discrete Mathematics Program Review (May 2006), at IAT, at Delta Technologies and at 21st Century Technologies.
- Five papers have been published or have been accepted for publication. One paper is currently in the review process, 2 papers are being revised for resubmission and six working papers are under construction with five soon to be submitted for publication.

The contributions of papers and dissertations that have not been addressed in the progress report for the previous reporting period are described in the Accomplishments and Associated Personnel sections of this report.

Associated Personnel

The following individuals have been associated with the project during this report period:

<i>Faculty:</i>	UT	J. Wesley Barnes, John J Hasenbein, Erhan Kutanoglu, David Morton, John Howell, Elmira Popova, Charles Groat, John Sharp, Gang Yu, Sahotra Sarkar
	AFIT	Lt Col Juan Sanchez, Capt Gary Kinney, James T. Moore
	USMA	LTC Garrett Lambert, LTC Robert Burks
	Wright State U.	Raymond Hill
	Texas A&M Med School	Reginald Baugh
<i>Consultants</i>		Dr. Bruce Colletti, LTC Kaye McKinzie PhD
<i>PhD Students:</i>		Capt Gary Kinney, Maj Gil Ness, Capt August Roesener, Michael Ciarleglio, Suzanne Pierce, Maj Jeffrey Havlicek, Dennis Michalopolous, Dmitriy Belyi, Jin Ho Kim, and Mei Yang
<i>MS Students:</i>		Leonisol Callaos, Zelong Liu, CPT Edward Teague, Ensign Brian Ross USN, Javier Barreiro and Jason Porter
<i>AMC:</i>		Mr. David L. Merrill, Maj David Van Veldhuizen PhD
<i>Mitre Inc.(USTRANSOM)</i>		Mr. Stuart Draper, Mr. Mark Surina
<i>Navitaire</i>		Dr. Julian Pachon, Dr. Michael Arguello
<i>Other Military:</i>		LTC John Harwig PhD
<i>Other Civilian:</i>		T. Glenn Bailey PhD, Boryana Dimova PhD, Michael J Patzek (AFRL/HECI), David W. Etherington (OTSYS), Edward DePalma (AFRL/IF)

UT Faculty

J. Wesley Barnes is the Consortium Principal Investigator (PI) at UT. He supervised to completion the MS work of Callaos, Barreiro and Teague and the doctoral work of Roesener. He is currently supervising the doctoral studies of Yang, Ness, Ciarleglio and Michalopolous and the MS studies of Liu, Teague, and Ross. He is currently serving on the PhD committee for Havlicik at AFIT and served on Burks' AFIT PhD committee who successfully defended his research on 30 June 2006. Dr. Barnes is a coauthor on each of the 8 papers that have been published, accepted for publication or were in the review process during this report period. He has also coauthored the other six working papers and several technical reports associated with the Consortium during this reporting period.

John J. Hasenbein is an Assistant Professor in the Graduate Program in ORIE at UT and is an NSF Early Faculty Career Development (CAREER) Awardee. His research interests mainly reside in the areas of stochastic analysis and networks of queues. He is currently serving on Yang's and served on Roesener's PhD committees.

Erhan Kutanoglu is an Assistant Professor in the Graduate Program in ORIE at UT and is an NSF Early Faculty Career Development (CAREER) Awardee. His area of research centers on large scale service part logistics systems for private sector industries. He served on Yang's and Roesener's PhD committees and on the MS committees for Barreiro, Liu and Ross.

Elmira Popova is an Associate Professor in the ORIE-UT program and a coauthor of 2 papers that have been published or have been in the review process during this report period. She was the second reader on Callaos' MS Report. Dr. Popova is an Associate Professor in the Graduate Program in ORIE at UT and is a recognized authority in probability theory and maintenance and repair theory.

Gang Yu is the Jack G. Taylor Regents Professor in Business Administration, Department of Management Science and Information Systems in Red McCombs School of Business at UT. He is an internationally renowned authority in the area of disruption management methodologies. Dr. Yu served on Yang's PhD committee until work considerations at Amazon.Com resulted in his being replaced by Dr. Julian Pachon.

David Morton is an Associate Professor in the ORIE-UT program, is a Fluor Centennial Teaching Fellow and is an NSF Presidential Early Career Award for Scientists and Engineers Awardee. He is internationally recognized for his work in stochastic optimization techniques. Dr Morton is serving of Yang's PhD committee and is co-supervising the doctoral research of Michalopolous.

John Howell is the a member of the Mechanical Engineering Faculty at UT in the thermal fluids arena and holds the both the Ernest Cockrell, Jr., Memorial Chair and the Baker Hughes Incorporated Centennial Professor at UT. He is also the Director of UT's Advanced Manufacturing Center, is a member of the National Academy of Engineering and a globally recognized authority in heat transfer. He is a coauthor of one of the papers accepted for publication during this report period.

Charles Groat, former Director of the US Geological Survey, very recently became the Director of the Center for International Energy and Environmental Policy and holds the Jackson Chair in Energy and Mineral Resources within the Jackson School of Geosciences at UT. Dr. Groat has agreed to collaborate with Professor Barnes in the application of metaheuristic methods applied to his varied interests.

John Sharp, Dave P. Carlton Centennial Professor in the Jackson School of Geosciences is supervising the doctoral research of Suzanne Pierce. Dr. Barnes assistance in the creation of Dr. Sharp's recently funded proposal, entitled "A Decision Support System for Public-Mediated Water Resource Planning," led to Dr. Barnes receiving \$5000 in salary support for the Summer 2006 term.

Sahotra Sarkar, a Professor in the Department of Philosophy, is an authority in the philosophy of biology and science. He is a coauthor of one of the working papers created during this report period.

AFIT Faculty

Capt Gary Kinney, under Dr. Barnes supervision, completed his dissertation, *A Group Theoretic Approach to Metaheuristic Local Search for Partitioning Problems*, in April 2005. He investigated group theoretic tabu search approaches to optimization problems that do not have a major permutation component. He is the coauthor of one of the papers that was accepted for publication during this report period.

Jim Moore has been the Consortium PI at AFIT since the project's inception. In past years, he has served on a number of Consortium PhD committees for students at UT and served on Roesener's PhD committee. His research supports the consortium and his research interests and teaching include integer programming, heuristic search methods, scheduling, and applications of operations research to military problems. Recent research has focused on tanker crew scheduling, the theater distribution problem, and the tanker employment problem.

Lt Col Juan Vasquez, AFIT-ENG, is working with AFRL/HECI on optimal use of mini UAVs for reconnaissance in urban arenas. In conjunction with AFRL/HECI, Dr. Vasquez is currently collaborating with Drs. Barnes and Morton on the development of a hybrid metaheuristic-stochastic optimization methodology to quickly construct robust solutions to these very difficult combinatorial optimization problems.

USMA Faculty

LTC Garrett Lambert completed his dissertation entitled, *A Tabu Search Approach to the Strategic Airlift Problem (SAP)* in the Fall of 2004. His presentation of a paper from this research at the 72nd MORS Symposium resulted in a nomination for the Barchi Prize. LTC Lambert is a coauthor of one of the papers that was in review during this report period.

LTC Robert Burks completed his doctoral dissertation entitled, *An Adaptive Tabu Search Heuristic for the Location Routing Pickup and Delivery Problem with Time Windows with a Theater Distribution Problem Application*, 30 June 2006 under the supervision of Dr. Jim Moore. Dr. Barnes served on LTC Burks' PhD Dissertation Committee.

Wright State University Faculty

Raymond Hill, winner of the 2000 Barchi Prize, is an Associate Professor of Industrial and Human Factors Engineering in the College of Engineering and Computer Science at Wright State University. Prior to that appointment he served on the faculty at AFIT/ENS. He is currently collaborating with the Consortium on a number of projects.

Texas A&M Medical School Faculty

Reginald Baugh, M.D., is the Director of the Division of Otolaryngology and Professor of Surgery at the Scott & White Clinic in Temple, Texas. He wishes to collaborate with Drs. Morton and Barnes in the development of a metaheuristic methodology to solve a difficult problem involving the simultaneous scheduling and sequencing of medical personnel to resolve resource/timing conflicts associated with the use of surgical theaters, patient care appointments and academic research.

Consultants

Bruce Colletti has actively participated as a consultant to the Consortium since its inception. His seminal work documented in his 1999 UT dissertation, *Group Theory and Metaheuristics*, is the foundation for much of the Consortium's efforts both in the theoretical and implementation domains. During this reporting period, Dr. Colletti has provided significant assistance in all facets of the Consortium's efforts. In particular, he has provided invaluable counsel in the research efforts in the arena of group theory and abstract algebra. He served on Kinney's PhD committee. He is a coauthor of one of the papers that was accepted for publication during this report period.

LTC Kaye McKinzie completed her dissertation entitled, *A Tabu Search Approach to Strategic Mobility Mode Selection*, in June 2005. She is also the principal coauthor of "A Review of Strategic Mobility Models Supporting the Defense Transportation System" published in the book, *Defence Transportation: Algorithms, Models, and Applications for the 21st Century* (2004) and is a coauthor of one of the papers accepted during this report period. LTC McKinzie is providing the Consortium her valuable expertise in the collaborative project ongoing with the Mitre Corporation. A briefing at the 74th MORS Symposium led to she and Dr. Barnes being nominated for the Barchi Prize.

PhD Students

Maj Gil Ness began his doctoral studies in the OR/IE program at UT in the Fall 2004 and is conducting preliminary dissertation research involved with the optimal routing and scheduling of PAX and cargo from supply points within CONUS to APOEs and SPOEs to optimally satisfy the stipulations of a specific TPFDD. He holds a Bachelor of Science in Operations Research from USAFA and Master of Science in Operations Research from AFIT. He has served as a Scientific Analyst at HQ AETC, HQ AFPC, OSD JSEAD JTF and as an Assistant Professor, Mathematical Sciences, at USAFA.

Capt August G. Roesener began his doctoral studies in the Fall of 2003. He finished and successfully defended his dissertation, *A Tabu Search Approach to the Airlift Loading Problem*, on 28 August 2006. He holds a Bachelor of Science in Operations Research from USAFA and Master of Science in Industrial and System Engineering from the University of Florida. Capt Roesener will join the faculty at AFIT in September 2006. He is a coauthor of a working paper written during this report period.

Mei Yang is a PhD candidate in the Graduate Program in ORIE at UT. She began her PhD studies in the Fall 2003. Her dissertation research, "Using Advanced Tabu Search Techniques to Solve Disruption Management Problems" is directed both at the theory of disruption management solution and at four specific application arenas. Ms. Yang advanced to candidacy in April 2005.

Michael Ciarleglio is a PhD student within the Computational and Applied Mathematics Graduate Studies Program. In order to become his PhD Supervising Professor, Dr. Barnes recently joined the Graduate Studies Committee for that program. Michael has been instrumental in Dr. Barnes' work with the Jackson School of Geology and with Dr. Sarkar in the Department of Philosophy. Michael is a coauthor of three of the working papers created during this report period.

Suzanne Pierce is a PhD student in the Jackson School of Geosciences near completion of her dissertation, "Decision support systems (DSS) in Hydrogeology." She is a coauthor on one of the working papers created in this

period. It is very likely that she will be joining the staff of the UT Center for International Energy and Environmental Policy in the Fall 2006.

Maj Jeffrey Havlicek is a PhD student at AFIT supervised by Dr. Moore. Dr. Barnes serves on his committee. His dissertation is tentatively entitled, "A Tabu Search Heuristic for Theater Fleet Routing with Refueling."

Dennis Michalopolous is a PhD student at UT. His work is being cosupervised by Morton and Barnes. His research will attack the interface between Barnes' work in direct search and Morton's work in stochastic optimization. The result of this work will greatly facilitate the solution of problems like the AFRL/HECI problem on determining the optimal use of mini UAVs for reconnaissance in urban arenas and Dr. Baugh's problem concerning the simultaneous scheduling and sequencing of medical personnel to resolve resource/timing conflicts associated with the use of surgical theaters, patient care appointments and academic research.

Dmitriy Belyi is a PhD student at UT with a strong background in Computer Science. He constructed a graphical user interface (GUI) to facilitate Roesener's research on air fleet loading. This was demonstrated at the AFOSR Optimization and Discrete Mathematics Program Review (May 2006).

Jin Ho Kim constructed a graphical user interface (GUI), at the request of Lt Col Van Veldhuizen (AMC), to facilitate the use of McKinzie's TPFDD automated editor/error corrector that was part of her dissertation research on the strategic mobility mode selection problem.

MS Students

Leonisol Callaos became an MS student in the Graduate Program in ORIE at UT in January 2003. Her research dealt with developing a valid statistical sampling methodology to determine whether and optimization landscape associated with a direct search on a practical sized combinatorial optimization problem is elementary. She finished her MS Report entitled, "Analysis of Random Walks on Landscapes of Combinatorial Optimization Problems Using Statistical Sampling" during this report period.

Zelong Liu became a student in the Graduate Program in ORIE at UT in the Fall 2004. Prior to joining the Consortium, Mr. Liu was an Assistant Professor and Research Associate for 10 years at the Chinese Academy of Sciences in Beijing, China. He has served as a PI on two research projects and is the author of 30 refereed publications in the subject arena of engineering thermophysics. He is currently working on an MS report dealing with the optimal design and usage of combined gas and steam turbine power generation using tabu search.

CPT Edward Teague holds a Bachelor of Science in Mechanical Systems from the United States Military Academy. He began his MS studies in ORIE at UT in the Summer 2004 and completed his work during this report period. His research focus was on reliability issues with the US military yielding an MS Report entitled "System of System Analysis of Tactical Military Operations".

Brian Ross, Ensign US Navy, is in the early stages of his MS research and has narrowed his possible topics for his MS report to two arenas.

Jason Porter was an MS student in the Mechanical Engineering Department at UT and finished his work during this report period. Dr. Barnes was the second reader on his report entitled, "Metaheuristic Optimization of A Discrete Array of Radiant Heaters." Porter is a coauthor on one of the papers accepted for publication during this report period.

Javier Barreiro is an MS student who was supervised by Dr. Barnes working on the development of a hybrid tabu search/constraint programming methodology. He completed his MS studies in August 2006.

AMC Personnel

Maj David Van Veldhuizen is the current lead for the AMC-AFIT-UT Consortium at AMC. He presently serves as the Modeling & Simulation Branch Chief, Directorate of Plans and Programs, Headquarters Air Mobility Command, Scott AFB, IL. He has an AAS degree in management information systems, a BGS in computer science from the

University of Nebraska-Omaha and an MS in applied mathematics both from the University of Nebraska, Omaha, and a Ph.D. in computer engineering from AFIT. He is a career US Air Force officer who has served in communications-computer, scientific, and program management positions. Currently an adjunct faculty member at AFIT, he has coauthored a book, book chapter, and over 30 papers. His current research interests include evolutionary computation, parallel/distributed systems, and scientific visualization. He served on the PhD committee of A.G. Roesener.

Mr. David L. Merrill holds the position of Chief, AMC Studies & Analysis Division (AMC/A59) at AMC. He has actively supported the Consortium's efforts from its inception.

Mitre Inc (USTRANSCOM)

Mr. Stuart Draper is a lead engineer at the Scott AFB site. He joined MITRE in 1992 after working in industry and more than 20 years in the United States Air Force. He supported United States Transportation Command's modeling, analysis, and mapping projects. These projects linked existing models into a composite transportation model that simulates military transportation from individuals' homes and resupply from the depot or factory until they arrive at the theater tactical assembly area or logistics support area. Mr. Draper developed the basic concepts (synchronized scheduling environment for execution in the DoD supply chain and an agent-based network design) being used in DARPA's Advanced Logistics Project. At the Air Mobility Command, he leads a group working on enterprise architecture planning, the corporate database, deployable communications, system acquisition, and technology transfer projects. He is the focal point for bringing more than \$1.5 million in technology transfer projects into the command during 1998. Mr. Draper has agreed to collaborate with the Consortium towards the goal of integrated previous and future research products into an end-to-end mobility modeling package.

Mr. Mark Surina is a high level with Mitre and is currently advising USTRANSCOM on Transformation Technology, inter-command collaboration, RFID technology and policy, Research and Development funding issues, large display technologies/methods (Knowledge Wall) and experimentation

Navitaire

Dr. Julian Pachon is currently serving on Yang's PhD Committee. He is a recognized expert on disruption management methodologies associated with flight operations for private sector airlines and is the General Director for Airline Operations at Navitaire.

Dr. Michael Arguello is also well known in the disruption management arena and both his past publications and current ready advice have helped Yang in her dissertation research.

Other Military

LTC John Harwig completed his dissertation project entitled, *An Adaptive Tabu Search Approach to Cutting and Packing Problems*, in 2003. The results of this research yielded new highly effective and efficient methodology that can be used in a number of military packing scenarios. The first paper generated from this research, "An Adaptive Tabu Search Approach for 2-Dimensional Orthogonal Packing Problems" has been published in the *Journal of the Military Operations Research Society (MORS)* during this reporting period.

Other Civilian

T. Glenn Bailey is the Director of Research, Modeling and Design for Delta Technology, Inc. He earned a BS in International Affairs from the United States Air Force Academy, a MA in Political Science from Oklahoma State University, a MS in Operations Research from AFIT and a PhD in Operations Research and Industrial Engineering from UT. He completed a 20 year career in the USAF serving as an Assistant Professor of Operations Research and Deputy Department Head for the Dept. of Operational Sciences at AFIT from 1996 to 1999. Dr. Bailey was instrumental in the initial planning, formulation and implementation of the AMC-AFIT-UT Consortium. He is currently serving on Mei Yang's PhD committee.

Boryana Dimova completed her dissertation, *Characterizing Neighborhoods Favorable to Local Search*, in November 2004. Her research has yielded five papers to this point in time, one published and one submitted in this report period. Dr. Dimova's work has shown, conclusively, that the search neighborhoods employed are integral to the success of tabu search methods. She continues her association with the Consortium while working as an R&D Associate for Austin Logistics in Austin, Texas.

Michael J. Patzek (AFRL/HECI) is the lead in the mini UAV project that Lt Col Vasquez and Drs. Barnes and Morton are collaborating on.

Dr. David Etherington, President of the On Time Systems Company, has conferred extensively with Dr. Barnes about the "squeaky wheel optimization" methods employed in WARP, a flight planner developed for AFRL/IF, which helps the USAF to find routes for cargo aircraft to optimize fuel usage from a world wide perspective. Collaborations with the Consortium in the future are possible.

Edward DePalma (AFRL/IF) introduced Dr. Barnes to Dr. Etherington and invited Dr. Barnes to a Conference of AMC, AFRL and USTRANSCOM personnel that led to the current collaboration between the Consortium and Mitre Inc. (USTRANSCOM). Mr. DePalma has also assisted the Consortium in identifying other possible projects and sources of future funding.

Publications

The following papers were published or accepted for publication in the current report period:

G. Kinney, J. W. Barnes, and B. Colletti, "A Reactive Tabu Search Algorithm with Variable Clustering for the Unicast Set Covering Problem", *The International Journal Of Operational Research*, 2006, (in press)

J. Harwig J.W. Barnes, and J. Moore, "An Adaptive Tabu Search Approach for 2-Dimensional Orthogonal Packing Problems", *Military Operations Research*, Vol. 11, No. 2, 2006.

B. Dimova, J. W. Barnes, and E. Popova, "The Characteristic Neighborhood Equation for an AR(2) Landscape", *Applied Mathematics Letters*, Vol. 19, No. 6, 2006.

K. McKinzie and J. W. Barnes, "A Tabu Search Approach to the Strategic Mobility Mode Selection Problem", *Air Force Journal Of Logistics*, 2006, (in press).

J. Porter, M. Larson, J.W. Barnes, and J. Howell, "Metaheuristic Optimization of A Discrete Array of Radiant Heaters", *Journal Of Heat Transfer*, October 2006, (in press).

The following papers have been under publication consideration during this report period:

Set Partitioning Embedded in a Tabu Search, (With T. Combs, J. Moore, and R. Hill), *European Journal of Operational research*.

Some Additional Properties of Elementary Landscapes, (with B. Dimova and E. Popova), *Applied Mathematics Letters*.

A Tabu Search Approach to the Strategic Airlift Problem, (with G. Lambert), *Journal of Military Operations Research*

The following working papers are planned for submission for publication:

Thermoeconomic Optimization of a Heat Recovery Steam Generator (HRSG) system using Tabu Search, (with Z. Liu and J. Howell), working paper.

An Advanced Tabu Search Approach to the Static Airlift Loading Problem (with A.G. Roesener, James T. Moore and D. Van Veldhuisen), working paper

A Comparison of Heuristic, Meta-Heuristic and Optimal Approaches to the Selection of Conservation Area Networks, (with M. Ciarleglio and S. Sarkar), working paper

A Generalized Strategic Dynamic Neighborhood Selection Methodology for Combinatorial Optimization Problems, (with M. Ciarleglio), working paper.

Using Advanced Tabu Search to Solve the Flight Rescheduling Problem, (with Mei Yang and Julian Pachon), working paper

Using Advanced Tabu Search with Dynamic Neighborhood Selection to Solve Water Aquifer Management Problems, (with S. Pierce and M. Ciarleglio), working paper.

The following doctoral dissertation research efforts were completed or were ongoing in this report period:

August G. Roesener, *A Tabu Search Approach to the Airlift Loading Problem*

Mei Yang, "Using Advanced Tabu Search Techniques to Solve Disruption Management Problems"

Gilbert Ness, "The Military Deployment CONUS Scheduling and Routing Problem"

Michael Ciarleglio, "A Generalized Tabu Search Methodology"

Dennis Michalopolous, "A Hybrid Tabu Search/Stochastic Optimization Methodology"

Interactions

As described above, in addition to the continuous interactions (achieved by telephone, email and physical visits) between the UT, AFIT, and AMC participants, the following more notable interactions also occurred:

- Mr. Stuart Draper and Mr. Mark Surina, both of the Mitre Corporation/USTRANSCOM, were present at a meeting of AMC, USTRANSCOM and AFRL representatives that occurred on 22 February 2006. Dr. Barnes and Dr. Moore were attended this meeting at the invitation of Mr. Ed DePalma. This invitation was issued after a host of emails and conversations between Barnes, Moore, DePalma, and Maj Todd Combs who was then the Program Manager for Dr. Barnes' AFOSR research. Maj Combs proactive support was the primary reason that this interaction resulted in Dr. Barnes and Dr. Moore attending the meeting.

During the meeting Dr. Barnes was invited to give an short impromptu presentation summarizing the Consortium's research and application efforts. Barnes' ten minute presentation was followed by a spirited thirty minute round table discussion by the attendees. As a by product of this discussion, Dr. Barnes and Dr. Moore were invited to talk in more detail about the Consortium not only with DePalma but also with Draper and Surina. This resulted in a visit to Mitre headquarters in O'Fallon, IL on 5 May 2006 where Moore and Barnes gave detailed presentations of the Consortium's work. Maj Gary Kinney and LTC Kaye McKinzie also attended this meeting. Additional discussion of this meeting and its outcomes are given in the Accomplishments section of this report.

During the 22 February meeting Barnes had an opportunity to discuss, in detail, the possibility of joint work with Dr. David Etherington. Subsequent to the meeting Mr. DePalma contacted Ms. Elizabeth Kean (AFRL/IFSA) who subsequently contacted Dr. Barnes about a forthcoming BAA that might be of interest to the Consortium.

- 21st Century Technologies is a "custom software development" firm based in Austin, Texas that has, as one of its products, a pallet loading algorithm for use by the US military. Dr. Barnes and Capt Roesener were invited to meet with the CEO and other representatives of 21st Century Technologies and to present an overview of the Consortiums efforts on 6 February 2006.

- The Institute for Advanced Technology (IAT) (<http://www.iat.utexas.edu/>) at UT was founded in 1990. IAT is an autonomous research unit under the Office of the Vice President for Research which supports the Army with basic and applied research. Dr. Barnes has continued to work with IAT and has had numerous meetings with representatives of IAT during the past year. Dr. Barnes is a consultant to IAT. The contacts at IAT have made it possible for Dr. Barnes to become knowledgeable on other military applications of operations research. Dr. Barnes' work with IAT led to interactions with the US Army Operational Testing Command dealing with the valid experimental design of operational tests..
- Dr. Sohotra Sarkar, of the UT Philosophy Department has worked with Dr. Barnes and Michael Ciarleglio in applying some of the Consortium's recently developed methodology to a complex species conservation problem. A working paper is being constructed to document this work.
- Numerous conversations involving Dr. Barnes, Dr. Glenn Bailey, Director of Research, Modeling and Design for Delta Technology, Inc. and other individuals have occurred during this report period to discuss mutual interests in the application of tabu search to air fleet logistics. A research funding plan was put into place to fund two doctoral students at UT. Unfortunately, a subsequent Chapter 11 filing by Delta Airlines has led to a postponement of that funding.
- Jason Porter was an MS student working for Dr. John R. Howell. Dr. Howell is a member of the Thermal/Fluids Systems faculty in the Mechanical Engineering Department at UT. At Dr. Howell's suggestion, during the Spring 2005 semester, Jason attended Dr. Barnes' graduate class on metaheuristic methods. Jason had no prior knowledge of tabu search. In only two months after the initial introduction to tabu search, Jason developed a markedly superior method (to previous methods) of solving an "inverse engineering problem" associated with radiation heat transfer. This *breakthrough* research is documented in the paper, "Using Tabu Search with Dynamic Neighborhood Selection to Solve Inverse Radiation Problems" which has been accepted by the *Journal Of Heat Transfer*. This opens a whole new application arena for tabu search. Dr. Howell promises to send more students to the metaheuristics class!
- Suzanne A. Pierce is a doctoral student in hydrogeology in the Jackson School of Geosciences at UT. Ms. Pierce is interested in applying metaheuristic techniques to otherwise intractable groundwater problems. This led Ms. Pierce to audit Dr. Barnes' graduate class on metaheuristic methods. Michael Ciarleglio, a PhD student in the Institute for Computational Sciences and Engineering at UT also attended Dr. Barnes metaheuristics class in Spring 2005. His interests matched with both Ms. Pierce and with Dr Barnes. This common interest led to Mr. Ciarleglio developing a modular advanced tabu search code to merge with existing software. This synthesis led to a proof of concept demonstration and a research proposal being funded for a practical scale implementation of this methodology. Other related groundwater problems are also being investigated from a tabu search perspective with Ms. Pierce and faculty members in the Department of Geological Sciences at UT.
- LTC McKinzie and Capt Roesener attended the 74th MORS Symposium at the USAF Academy (13-15 June 2005). LTC McKinzie presented "A Tabu Search Approach to the Strategic Mobility Mode Selection Problem" and Maj Roesener presented "An Advanced Tabu Search Approach to the Static Airlift Loading Problem." Numerous interactions were enjoyed with civilian contractors and with military personnel.

Accomplishments

As is clear from the above paragraphs, the twelve months of this project report period have been filled with accomplishments. There have also been notable new scientific developments and findings associated with the Consortium's work. While many discoveries have been made, the more important of these have been reported in the papers, reports, and dissertation that have been published, accepted for publication, or submitted for publication consideration.

We now briefly summarize the accomplishments detailed in those documents.

First, we focus on "transitions" (cases where our work is slated for use in either an AMC technology application or in an important application arenas essential to the economic and environmental well being of the nation.).

The groundbreaking work of the Consortium's first six years of work has received highly positive reviews from AMC. In a letter of support for the Consortium's Phase III proposal, Mr. David L. Merrill, Chief, AMC Studies & Analysis Division, AMC/A59 stated that this work "is beginning to impact AMC's modeling and simulation tools, and the speed and veracity of the analyses we perform. ... My folks and I are excited by the potential efficiencies this can bring to our operations."

The work documented in Barnes, J.W., V. Wiley, J. Moore, and D. Ryer (2004), in Crino, Moore, Barnes, and Nanry (2004), McKinzie and Barnes (2004), Harwig, Barnes and Moore (2006), Lambert and Barnes (2005) and McKinzie and Barnes (2006) have all received similar acceptance by AMC. The details associated with Lambert and Barnes (2005), McKinzie and Barnes (2006) and Harwig, Barnes and Moore (2005) were fully summarized in last year's progress report where the potential for massive improvements in the efficiency and effectiveness of AMC's operations were made clear.

Barnes, Lambert and McKinzie briefed at the 20 May 2005 AMC-AFIT-UT meeting. At that meeting AMC representatives *specifically requested* that a module be created, embodying an enhanced version LTC Harwig's 2-dimensional packing methodology, *for inclusion into their primary planning tool*, AMOS. Among the enhancements requested was a proper consideration of restrictions on weight balance and center of gravity to enforce pitch and roll constraints on military aircraft.

Given that directive, the Consortium responded with an intense research effort culminating in the dissertation research of Roesener and the working paper of Roesener, Barnes, Moore and Van Veldhuizen (2006). This research addressed both the channel and contingency instances of air fleet loading at an APOE. In this process, Capt Roesener took sufficient classes to become a Certified Load Planner completely conversant with the loading methods currently employed by the USAF.

The methods that Roesener developed have the potential to radically improve the loading practices of the USAF, greatly improving the loadings in terms of higher utilization, superior weight balance and center of gravity while reducing, on average, the number of sorties required by about 5%. The potential savings due to using this methodology could be hundreds of millions of dollars per year.

McKinzie and Barnes (2004) details the "end-to-end mobility problem" that comprises the ultimate goal for the UT-AFIT-AMC Research Consortium. The current discussions with Mitre/USTRANSCOM are directed at acquiring sufficient resources to integrate the methodologies described in the papers in Appendix A (plus 2 or 3 additional component methodologies) into a holistic approach to streamline the logistics needs of the US military establishment. Prior to the UT-AFIT-AMC Research Consortium's achievements, this goal was deemed impossible. The methods that the Consortium has developed have made this task distinctly achievable. For example, the problem addressed in Barnes, Wiley, Moore and Ryer (2004) was previously solved by a team of six to ten analysts using a discrete emulation program and would take that upwards to two and one-half months to construct a single feasible solution. The TS methodology described in Barnes, Wiley, Moore and Ryer (2004) showed that it was possible to generate an ensemble of superior solutions, without human intervention, in about *four hours*. Similar comparative results have been dramatically illustrated for the techniques detailed in the other application papers cited above. With Mr. Draper's enthusiastic approval and assistance, we are working to formulate a research proposal in furtherance of our stated goal.

Recently, the state of Texas has mandated that every groundwater management area must produce a viable plan for their future water resources. Prior planning tools and models have been insufficient; none of them are capable of finding optimal management policies for key watershed issues. A general purpose tabu search (MASTS) spearheaded by Michael Ciarleglio has been integrated into the Groundwater Decision Support System created by Suzanne Pierce. This search directly addresses management variables such as well locations, drought management policies, and future pumping allocation. A dynamic response mechanism helps navigate the search space efficiently, discovering counter-intuitive new alternatives which may help preserve key environmental features while meeting water demand. Thus, the foundational work of the consortium has led directly to powerful methods to deal with groundwater management where not even an approximation to such tools existed before.

The same tabu search engine (MASTS) has been re-tooled to design conservation areas for endangered species, deciding which plots of land should be preserved. Previous attempts have not addressed the inherent spatial aspects of the problem regarding the shape and distribution of the preserved areas. Furthermore, optimization quickly becomes intractable as problem size increases. The first version of the search overcomes both of these issues, providing greater levels of control for decision makers. We expect that this methodology will prove to be far superior to other existing techniques.

Disruption management is a key capability required in any complex system subject to unpredictable, unavoidable and unwanted alterations. Any military activity of a practical scope comprises such a system. The best current practical work in disruption management is being performed in the context of disruptions in the operations of civilian sector airlines. Mei Yang's research with the help of Delta Technology and Navitaire is allowing the Consortium to learn and compete with the best current practitioners. The foundational knowledge and framework gained from this work should be easily transferred to military logistics considerations.

Second, we consider the theoretical accomplishments that have significantly expanded the frontiers of knowledge.

First, we address the theoretical contributions associated with neighborhood and landscape theory.

Our previous papers associated with landscape theory (detailed in previous progress reports) and the more recent published paper (Dimova, Barnes and Popova 2006a) and submitted paper (Dimova, Barnes and Popova 2006b) document our highly successful work directed at discovering the underlying structures governing local search neighborhoods and how they contribute to the success of tabu search approaches. While important to any tabu search algorithm, this knowledge will also enhance the use and effectiveness of any other metaheuristic technique. Research is still ongoing on the working paper, "Using a Discrete Dynamic Systems Approach to Analyze Tabu Search Sequences." (Meyer and Barnes, 2006)

Spurred by the knowledge gained in our work on elementary landscapes, our currently most active area of theoretical research deals with the formulation and understanding of strategic dynamic neighborhood selection (SDNS) methods for tabu search approaches. We are pushing this investigation on two fronts: (1) specially tailored SDNS techniques applied to specific problems where inherent structures exist and can be directly exploited and (2) the development of SDNS methods that are applicable to more general classes of problems.

Examples of successful tailored SDNS methods may be seen in Harwig, Barnes and Moore (2006), Porter et al. (2006), Kinney, Barnes and Colletti (2006), and Roesener, Barnes, Moore and Van Veldhuizen (2006). In each of these papers, an in-depth understanding of the problem structure illuminated strategic circumstances occurring during the search that would make one or more particularly specified neighborhoods dramatically helpful in improving the effectiveness and efficiency of the search.

The formulation of SDNS methods that are effective on a more general class of problems is in its infancy. Our first attempt at this (Kinney 2005) was to attack the general integer programming problem by using an approach based on Gomory's Group Minimization Problem (GMP). Any algorithm that solves the GMP solves the general ILP. The multi-dimensional knapsack problems (MDKP), both integer and binary, and set covering problems (SCP), both unicast and weighted, were used to test the versatility of the approach. GTTS-GMP did not perform as well as we hoped on very large, sparse SCPs. We will continue to work on GTTS-GMP perspective.

A different approach to more general SDNS methodologies is described in Ciarleglio and Barnes (2006) and variants of that technique are successfully applied in Pierce, Ciarleglio and Barnes (2006) and in Ciarleglio, Barnes and Sarkar (2006).

Conclusion

In summary, the last 12 months have been intriguing, challenging, and productive. Much has been accomplished and we eagerly look forward to the future challenges that will be met and overcome in achieving the Consortium project objectives.

We stand ready to answer any questions about the project and will provide any additional materials, such as papers and manuscripts upon request.

References Cited in this Report

- Barnes, J.W., V. Wiley, J. Moore, and D. Ryer, Solving the Aerial Fleet Refueling Problem using Group Theoretic Tabu Search, , *Mathematical and Computer Modeling* , V39, No 6-8, 2004; also published in *Defence Transportation: Algorithms, Models, and Applications for the 21st Century*, Eds. R.T. Brigantic and J.M. Mahan, Elsevier Science and Technology Books, 2004.
- Barnes, J.W., Z. Liu and J. Howell, Thermoeconomic Optimization of a Heat Recovery Steam Generator (HRSG) system using Tabu Search, working paper.
- Ciarleglio, M., J.W. Barnes, and S. Sarkar, A Comparison of Heuristic, Meta-Heuristic and Optimal Approaches to the Selection of Conservation Area Networks, working paper
- Ciarleglio, M. and J.W. Barnes, A Generalized Strategic Dynamic Neighborhood Selection Methodology for Combinatorial Optimization Problems, working paper.
- Ciarleglio, "A Generalized Tabu Search Methodology, ", PhD Dissertation in progress
- Combs, T., J. Moore, R. Hill and J.W. Barnes, Set Partitioning Embedded in a Tabu Search, *European Journal of Operational research* in review.
- Crino, J., J. Moore, J.W. Barnes, and W. Nanry, Solving The Military Theater Distribution Vehicle Routing and Scheduling Problem Using Group Theoretic Tabu Search, *Mathematical and Computer Modeling* , V39, No 6-8, 2004; also published in *Defence Transportation: Algorithms, Models, and Applications for the 21st Century*, Eds. R.T. Brigantic and J.M. Mahan, Elsevier Science and Technology Books, 2004.
- Dimova, B, J.W. Barnes, and E. Popova, The Characteristic Neighborhood Equation for an AR(2) Landscape, *Applied Mathematics Letters*, Vol. 19, No. 6, 2006a
- Dimova, B, J.W. Barnes, and E. Popova, Some Additional Properties of Elementary Landscapes, in third review with *Applied Mathematics Letters*, 2006b
- Harwig, J., J.W. Barnes, and J. Moore, An Adaptive Tabu Search Approach for 2-Dimensional Orthogonal Packing Problems, *Military Operations Research*, Vol. 11, No. 2, 2006.
- Kinney, G., *A Group Theoretic Approach to Metaheuristic Local Search for Partitioning Problems*, PhD Dissertation, The University of Texas at Austin, 2005
- Kinney, G. , J. W. Barnes, and B. Colletti, "A Reactive Tabu Search Algorithm with Variable Clustering for the Unicast Set Covering Problem", *The International Journal Of Operational Research*, 2006, (in press)
- Lambert, G. and J.W. Barnes, A Tabu Search Approach to the Strategic Airlift Problem, in second review with the *Journal of Military Operations Research*
- McKinzie, K., and J.W. Barnes, A Review of Strategic Mobility Models Supporting the Defense Transportation System, *Mathematical and Computer Modeling*, V39, No 6-8, 2004; also published in *Defence Transportation: Algorithms, Models, and Applications for the 21st Century*, Eds. R.T. Brigantic and J.M. Mahan, Elsevier Science and Technology Books, 2004.
- McKinzie, K., *A Tabu Search Approach to Strategic Mobility Mode Selection*, PhD Dissertation, The University of Texas at Austin, 2005
- McKinzie, K. and J.W. Barnes, A Tabu Search Approach to the Strategic Mobility Mode Selection Problem, *Air Force Journal Of Logistics*, 2006, (in press)
- Meyer, T. and J.W. Barnes, Using a Discrete Dynamic Systems Approach to Analyze Tabu Search Sequences, working paper
- Michalopoulos, "A Hybrid Tabu Search/Stochastic Optimization Methodology" , PhD Dissertation in progress
- Ness, G., "The Military Deployment CONUS Scheduling and Routing Problem" , PhD Dissertation in progress
- Pierce, S., M. Ciarleglio, and J.W. Barnes, Using Advanced Tabu Search with Dynamic Neighborhood Selection to Solve Water Aquifer Management Problems, working paper.
- Porter, J., M. Larson, J.W. Barnes, and J. Howell, "Metaheuristic Optimization of A Discrete Array of Radiant Heaters", *Journal Of Heat Transfer*, October 2006, (in press).
- Roesener, A.G., J.W. Barnes, James T. Moore and D. Van Veldhuisen, An Advanced Tabu Search Approach to the Static Airlift Loading Problem, working paper
- Roesener, A.G., *A Tabu Search Approach to the Airlift Loading Problem*, PhD Dissertation, The University of Texas at Austin, Austin, Texas, 2006.
- Yang, M., J.W. Barnes, and J. Pachon, Using Advanced Tabu Search to Solve the Flight Rescheduling Problem, working paper

Yang, M. "Using Advanced Tabu Search Techniques to Solve Disruption Management Problems", PhD Dissertation in progress

Appendix A

Solving the Aerial Fleet Refueling Problem using Group Theoretic Tabu Search, (with V. Wiley, J. Moore, and D. Ryer), *Mathematical and Computer Modeling*, 6-8, 2004.

Solving The Military Theater Distribution Vehicle Routing and Scheduling Problem Using Group Theoretic Tabu Search, (with J. Crino, J. Moore, R. Hill), invited paper for a special issue of *Mathematical and Computer Modeling*, 6-8, 2004.

Solving The Military Theater Distribution Vehicle Routing and Scheduling Problem Using Group Theoretic Tabu Search, (with J. Crino, J. Moore, R. Hill), *Mathematical and Computer Modeling*, 6-8, 2004.

K. McKenzie and J.W.Barnes, "A Review Of Strategic Mobility Models Supporting The Defense Transportation System", *Defence Transportation: Algorithms, Models, and Applications For The 21st Century*, pp.839-868, edited by R.T.Brigantic and J.M.Mahan, 2004.

A Tabu Search Approach to the Strategic Mobility Mode Selection Problem, (with K. McKinzie) to appear in the *Air Force Journal of Logistics*, Summer 2006.

A Tabu Search Approach to the Strategic Airlift Problem, (with G. Lambert), reviewed by the *Journal of Military Operations Research*

An Advanced Tabu Search Approach to the Static Airlift Loading Problem (with A.G. Roesener, James T. Moore and D. Van Veldhuisen), working paper